Blocked Flue Detection Methods and Systems

Field

The present invention relates to HVAC heating systems, and more particularly, to monitoring and burner control methods and systems for such HVAC heating systems.

Background

HVAC heating systems typically include a combustion chamber that works cooperatively with a burner. The burner receives fuel from a fuel source, and when ignited, provides the necessary heat to a controlled space. Gases from the combustion chamber typically exit the combustion chamber and the controlled space through a flue.

A problem recognized with some HVAC systems is that if the flue becomes sufficiently blocked or otherwise obstructed, gasses generated in the combustion chamber may fail to exit the chamber and thus the controlled space. Such gasses can back up into a house or building, creating hazardous conditions for occupants. A flue can become blocked for any number of reasons, including nesting animals, fallen sticks/leaves, ice blockages, and/or other objects or materials that may become lodged in the flue. In some cases, the flue may become sufficiently blocked by simply by build up of ash, creosote and/or other combustion waste vented from the chamber.

To help detect such flue blockages, pressure sensors, flow sensors, temperature sensors, and the like, are often provided in the flue to detect insufficient flow of exhaust gases through the flue. However, it has been found that these additional sensor elements, wiring, and connections can unduly increase the cost and possibly reduce the reliability of the HVAC system.

Summary

The present invention is directed at systems and methods for detecting flue blockages without the addition of numerous additional sensor elements, wiring, and connections that can unduly increase the cost and possibly reduce the reliability of the HVAC system. In virtually all combustion systems, including HVAC heating systems, a flame sensor is already provided to detect if flame is present before the main fuel is turned on, and/or if the flame is lost after initial ignition and while the main fuel is turned on. If either of these conditions occurs, the HVAC system is typically shut down. In one illustrative embodiment of the present invention, the flame sensor is also used to detect a flue blockage.

During a heating cycle, a controller or the like may monitor the output signal from the flame sensor, and detect changes in the detected light output. By examining the detected light output, in some cases over time, the controller may determine if a flue has become blocked or even partially blocked.

In some embodiments, and because of normal flame signal variations, the output signal from the flame sensor may be time-averaged over a predetermined time period. The time averaged value may then be compared to a reference value to determine whether there is a flue blockage. In some embodiments, the reference level may be updated, from time to time, to reflect ongoing flame conditions.

Brief Description of the Drawings

Figure 1 is a highly diagrammatic schematic of an HVAC system;

Figure 2 is a flow chart for an illustrative method for detecting flue blockage;

Figure 3 illustrates a graph of an idealized reference value and sensor output for an illustrative flue blockage detection method;

Figure 4 is another flow chart showing steps within an illustrative method for detecting flue blockage;

Figure 5 is a graph of actual sensor output under varying flue conditions; and

Figure 6 is another graph of actual sensor output under varying flue conditions.

Detailed Description

The following detailed description should be read with reference to the drawings. The drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the invention. While many of the embodiments described here relate to oil-burning HVAC systems, it should be recognized that the present invention is not so limited, and may be applied to any HVAC system that includes a flame and a flue. It should also be recognized that the phrase "flue blockage", as used herein, includes both partial and complete flue blockages, unless specifically noted otherwise.

Figure 1 illustrates an oil-burning HVAC system, generally shown at 10, which includes a combustion chamber 12 that works cooperatively with a burner 14. The burner 14 receives fuel from a fuel source 16. The burner 14 includes a burner tube 18 that extends into the combustion chamber 12. A flame 20, when present, may extend out of the burner tube 18, as shown. A blower 22, which typically includes a blower fan shutter, provides forced air into the chamber 12 and is often controlled to optimize the flame 20. The blower 22 may also be used to purge vapors and gasses from the chamber 12 before and/or after a heating cycle. For example, during each heating cycle, the blower 22 may be used to purge the chamber 12 prior to flame ignition, as well as after the flame is turned off.

Gases from the combustion chamber 12 exit through a flue 24. In the illustrative embodiment, the burner 14 includes a flame sensor 26 that monitors the flame 20 through the burner tube 18. Often, the flame sensor 26 will be an optical sensor, such as a cadmium sulfide flame sensor, but it is recognized that any suitable flame sensor may be used.

In typical operation, a controller 28 receives a call for heat from a thermostat 30. The controller 28 then sends a call for activation of the burner 14 and blower 22. The blower 22 may remove any residual gasses or vapors from the chamber 12 prior to flame ignition. Then, an ignition sequence may start, with the burner 14 operated to start a flame 20 in the burner tube 18. The flame sensor 26 may be used to monitor the ignition sequence, and determine whether the fuel provided by the burner 14 properly ignites. If the fuel does not properly ignite, the controller may retry the ignition sequence, and eventually move into a lockout state, where the flow of fuel is stopped. Once in the lockout state, a technician may be needed to reset the system, since failure to ignite often indicates a problem with the system and/or unsafe operating conditions.

As indicated above, the flue 24 may become blocked for any number of reasons, including nesting animals, fallen sticks/leaves, ice blockage, and/or a variety of objects or materials that can become lodged in the flue 24. The flue 24 can also be blocked by buildup resulting from ash, creosote and other combustion waste vented from the chamber 12. If sufficiently obstructed, the flue 24 may fail to allow sufficient gasses from the burning of fuel to exit the chamber 12. Such gasses can back up into a house or building, creating hazardous conditions for occupants. Carbon monoxide or other gas detectors can be used to determine whether the atmosphere near the system 10 is becoming hazardous. These sensors only detect such problems after the interior air has

become contaminated. Also, such sensors complicate wiring and layout, as well as increasing costs, of a system 10.

Many HVAC systems operating in a series of sequential heating cycles to maintain a desired temperature in an inside space relative to a temperature set point. Each heating cycle is typically initiated by a call for heat, typically provided by a thermostat or other control device. Each heating cycle typically ends when the HVAC system has satisfied the current heating needs of the inside space, which is typically also indicated by a thermostat or the like.

Figure 2 is a flow chart showing an illustrative method for detecting a flue blockage in accordance with the present invention. The illustrative method begins in a wait for call state 50, indicating that the system is not operating the burner and is waiting for a call for heat. When a call for heat 52 occurs, the system may enter startup state 54, which may include a number of steps for determining whether it is safe to ignite the burner 18. If an unsafe condition is detected, the system may enter a lockout state 58, where the burner will not be operated or ignited, sometimes until a service technician performs maintenance.

If startup 54 is passed safely, the system enters ignition state 56. During ignition state 56, the system begins feeding fuel to a burner while also providing for ignition. During ignition, fuel is typically fed past a pilot light, which then ignites the burner, or fuel is provided to the burner and a sparking device provides a spark that directly ignites the burner. Also during ignition state 56, a flame sensor, such as flame sensor 26 of Figure 1, may be used to observe the flame produced by the burner and determine whether a flame has been ignited. If the flame fails to ignite within a predetermined time

period, the system may enter the lockout state 58. If the flame does ignite and is sensed, then the system may enter a run state 60.

The flame sensor may be any type of sensor capable of detecting a flame. For example, the flame sensor may be an optical device that has an electrical characteristic that changes when light is incident on a window or other area of the flame sensor. Although not limiting, one such flame sensor includes a resistive element that varies in resistance in response to visible or other wavelengths of light. The flame sensor may provide a voltage, current, frequency, or any other suitable output signal, as desired. Semi-conducting devices and/or photodiodes may also be used, as well as non-optical devices such as heat sensitive devices, if desired.

In the illustrative example of Figure 2, the run state 60 shows two steps, though other steps may also be part of the run state 60. In Figure 2, the run state 60 includes the step of observing the flame 62 to capture a flame value or series of flame values, and the step of comparing the flame value or values to a reference value 64. In some cases, the flame value is derived from the output or a series of outputs from the flame sensor, and is preferably a quantitative (rather than qualitative) output of the flame sensor. For example, some flame sensors may be adapted to only provide a qualitative output of "FLAME ON" or "FLAME OFF". For the present invention, however, the flame sensor preferably provides a quantitative output (outputs that may take on a number of values across a range). For example, one quantitative output would be a resistance value that, in response to light, varies from 300 ohms to 500 ohms of resistance. Other examples include an avalanche photodetector that outputs a current in response to incident light, or a phototransistor that receives light at the base of a bipolar junction transistor. The

quantitative output may take on a number of forms including resistance, voltage, current, frequency, or any other suitable form.

In the run state 60, the flame is observed at 62 and compared to a reference at 64. In some embodiments, an acceptable range is defined around the reference value. If, in a numerical example, the flame output, or a flame value derived therefrom, is a measured resistance that varies between 150 and 500 ohms, the reference value may be chosen as the resistance measured when the burner is on and known to be correctly operating with proper ventilation and exhaust through the flue. Continuing with the numerical example, if the measured resistance is 300 ohms under these conditions, then it may be determined that a tolerance of 75 ohms is allowed, such that the acceptable reference range is 300 +/- 75 ohms, i.e. from 225 to 375 ohms. Thus, as long as the flame output, or a flame value derived therefrom, is measured and found to be within this range, the numerical example will continue to operate in the run state 60 until either the call for heat is satisfied or the flame output (or flame value) is no longer in the acceptable range (barring, of course, some other intervening event such as a power outage). If the flame output, or a flame value derived therefrom, falls outside the acceptable reference range, and in some cases falls outside the acceptable reference range for a predetermined duration of time, the system may enter the lockout state 58. If the call for heat is satisfied without the flame output (or flame value) falling outside the acceptable range, then the system may return to the wait for call state 50.

Upon startup of the combustion process, the flame sensor output may change a relatively large amount for a period of time, such as 3 minutes. After this period of time, however, the combustion process may become relatively stable. To help reduce the possibility of assigning a reference value using an output value of the flame sensor during

the startup of the combustion process, the method may include a delay step that delays the assigning of a reference value for a period of time after the ignition state 56 is entered. Alternatively, or in addition, a value produced by the flame sensor may be periodically recorded during the startup of the combustion process, and each value may be compared to the previous value or several previous values. In one illustrative embodiment, if the last "n" (where "n" is an integer greater than zero) values are monotonically increasing (or decreasing), each by more than a predetermined amount, then a reference value is not assigned. Once the combustion process becomes relatively stable, the last "n" values will no longer be monotonically increasing (or decreasing), each by more than a predetermined amount, and thus a reference value may be assigned.

To help compensate for normal flame variation, it may be desirable to take a number of readings from the flame sensor over a period of time, and average those readings to arrive at a more representative value of true flame conditions. For example, to arrive at a flame value, three flame sensor readings may be taken over a ten second period of time, and mathematically averaged to provide the flame value. Likewise, to arrive at a reference value, three flame values, taken over different periods of time, may be mathematically averaged to provide the reference value. The number of readings and time period of these readings may be varied, depending upon the particular characteristics of the system.

In some illustrative embodiments, and during the run state 60, the reference value may be periodically reset. Resetting the reference value may or may not be provided, depending on the appliance characteristics, as well as other factors. For example, it may be desirable to reset the reference value when windows and/or doors have been opened or

closed within the structure, and/or when any other change in system or environmental conditions occurs.

In one embodiment, the reference value is reset to a new measured value, or a new "averaged" value as described above, at a predetermined time interval, such as every five minutes. The resetting of the reference value may or may not include various checks. For example, hard upper and/or lower limit checks may be set for the reference value, and the system may prevent the resetting of the reference value outside of these limits.

Other checks may also be performed. For example, and continuing with the above numerical example, individual measured resistance values may be taken at a predetermined number (e.g. three) of consecutive time periods (e.g. one minute). One illustrative check may determine if any of the individual measured resistance values varies from another by more than five ohms. If not, the reference value may be reset to a new reference value. The new reference value may be an average of the individual reference values. Table 1 below illustrates one example:

Time	Measured	Ref	Tolerance	Δ
Minute 1	318	300	75	18
Minute 2	285	300	75	15
Minute 3	311	300	75	11
Minute 4	314	300	75	14
Minute 5	310	300	75	10
Minute 6	315	313	75	3.3
Minute 7	325	313	75	12
Minute 8	299	313	75	14

Table 1

Referring to Table 1 above, after the first three minutes of a heating cycle, the individual measured resistance values vary from one another by more than five ohms, and thus, the reference value "Ref" is not reset. Likewise, at minute four, the individual measured

resistance values taken at minutes two through four vary from one another by more than five ohms, and thus, the reference value is not reset. At minute five, the individual measured resistance values taken at minutes three through five also vary from one another by more than five ohms, and thus, the reference value is not reset. At minute 6, however, the individual measured resistance values taken at minutes four through six do not vary from one another by more than five ohms, and thus, the reference value is reset to the average of the individual measured resistance values taken during minutes four through six. At minutes 7 and 8, the individual measured resistance values taken from the current and two previous minutes vary from one another by more than five ohms, and thus, the reference value is not reset.

Other checks may also be performed, as desired. For example, there may be a limit to the amount of adjustment that may occur during any single reset, such as five ohms. Checks may also be performed to identify trends or changes that may indicate that a flue is becoming gradually blocked, as by an animal building a nest over time.

Because many HVAC systems already include a flame sensor and are controlled by a microcontroller, the present invention may be incorporated into existing HVAC systems by simply providing new software to the microcontroller. This may make the present invention a less expensive way to provide blocked flue detection to existing and new systems. It should be recognized, however, that the present invention is not so limited, and may be implemented in any suitable manner, including using analog timers, comparators and/or discrete logic gates, as desired.

Figure 3 illustrates a graph of an idealized reference value and sensor output for an illustrative flue blockage detection method. The illustrative graph shows the resistance of a flame sensor versus time. A line is shown fitted to idealized measured

resistance values, which are shown by the asterisks. At a first time t1, shown at 80, a call for heat occurs, and so an ignition sequence begins. In the illustrative embodiment, and as ignition occurs and the flame begins to glow and burn brightly, the resistive output of the flame sensor drops until, at time t2 at 82, it begins to level off. The illustrative example uses a flame sensor that has an effective resistance that goes down when exposed to light; this may occur, for example, with some semiconductors as well as a variety of other devices. Other devices that undergo different changes may be used. At a third time t3, as shown at 84, the flue is blocked, causing a significant change in the flame sensor output.

Typically there will be some variation in the output value during operation. In the short term, there will be some random noise that causes variation in the measured resistance values. Over a longer time period, as shown from time t2 to time t3, and as shown at 84, there may be some device drift or changes caused by changing conditions in the environment such as doors and/or windows opening or closing.

Shown on the separate lower scale 86 is a reference value. During an ignition stage 88, the reference value is not relevant and in some embodiments, may not even be calculated. As steady state operation is achieved, as shown between times t2 and t3, the reference value shown at 90 may occasionally be reset, to compensate for drift over time as well as any changing system and/or environmental conditions. In the example shown, the reference value 90 is updated at five minute intervals, though shorter and longer intervals may be used. In some embodiments, and as part of the adjustment of the reference value 90, hard upper and lower limits 94 may be defined, preventing the reference value 90 from reaching a value that is out of an acceptable reference range.

Figure 4 is another flow chart showing steps of an illustrative method for detecting a flue blockage. In the illustrative embodiment, the flow chart shows steps that may occur within a run state 100. At the start of a new time period, shown at block 102, the illustrative method determines whether it is time to reset the reference value, as shown at block 104. As noted above, this may occur at, for example, five minute intervals. Alternatively, or in addition, the reference value may be reset when the measured resistance values from the flow sensor have moved away from the current reference value, often due to changing system or environmental conditions.

If it is time to reset the reference value, and in the illustrative embodiment, it is first determined if the flame level is currently varying too much, as shown at block 106. If the flame level is currently varying by more than a predetermined amount, the reference value may not be reset because the measurements may be unstable, and control is passed to block 112 where a new flame level is observed. If the flame level is not varying by more than a predetermined amount, control may be passed to block 108. Block 108 may average the flame level for a number of past several time periods, as shown at 108, and the reference value is reset to the new "average" value, as shown at 110. Control is then passed to block 112, where a new flame level is observed.

Once a new flame level is observed at block 112, the measured flame level (or an average of a number of flame levels) may be compared to the reference value. In the illustrative embodiment, block 114 determines if the measured flame level (or an average of a number of flame levels) falls outside of a range defined by the reference value plus or minus a reference threshold. The reference threshold defines an acceptable range around the reference value. If the flame level (or an average of a number of flame levels) does not fall outside of the range defined by the reference value plus or minus the

reference threshold (i.e. the flame level is within the acceptable range around the reference value), then control is passed to block 116, which waits for the next time period to begin. If, however, the measured flame level (or an average of a number of flame levels) falls outside of the range defined by the reference value plus or minus the reference threshold, control is passed to a lockout block 118.

Figure 5 is a graph 200 showing an actual sensor output versus time under varying flue conditions. To gather data for the graph 200, an oil burner having a resistive output flame sensor was coupled to a flue equipped with a device that allowed the flue to be selectively opened and closed. The burner also included a damper that could be selectively opened and closed. The damper was used to control the oxygen content in the combustion chamber, and thus the flame characteristics. For these tests, the flame sensor was of a type that decreased in resistance when exposed to light, although as indicated above, any type of flame sensor may be used.

In Figure 5, the graph 200 shows a trace 202 that corresponds to the resistance value of the flame sensor versus time. Initially, with the flue open (before time 206), the resistance of the flame sensor varies at between 490 and 570 ohms. At time 206, the flue is closed. As can be seen, the resistance curve 202 of the flame sensor drops significantly, and begins varying in the range of about 210 to 440 ohms. The present invention may be used to monitor the resistance of the flame sensor, and detect the change in resistance in the flame sensor output that occurs at time 206 and determine that a blocked flue has occurred.

Figure 6 is another graph 210 showing an actual sensor output under varying flue conditions. The graph 210 was gathered in a similar fashion to that of Figure 5. However, the burner was operated under different and more inefficient conditions for

Figure 6. Before a first time 214, the graph illustrates a resistance curve 212 with the flue open. When the flue is closed at first time 214, the resistance curve 212 begins to climb steadily. Like above, the present invention may be used to monitor the resistance of the flame sensor, and detect the change in resistance in the flame sensor that occurs beginning at time 214 and determine that a blocked flue has occurred.

Figures 5 and 6 illustrate that the flame sensor output may vary in different ways when the flue becomes blocked or is otherwise closed, depending on system and environmental conditions. Under some conditions, more light will reach the flame sensor when the flue is blocked, while under other conditions, less light will reach the flame sensor. It is believed that under some conditions, a flue blockage may produce a sooty flame, which may burn more brightly than an efficient flame. Under other conditions, it is believed that a flue blockage may cause the air between the flame and the flame sensor to become dirty and sooty, which can block out a portion of the light emitted by the flame. According to the present invention, both of these conditions can be detected, because it is the change (positive or negative) in the output of the flame sensor that can be detected to determine that a flue blockage has occurred.

Those skilled in the art recognize that the present invention may be manifested in a variety of forms other than the specific embodiments described and contemplated herein. Accordingly, departures in form and detail may be made without departing from the scope and spirit of the present invention as described in the appended claims.